REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
16-07-2015	Final	

4. TITLE AND SUBTITLE Test Operations Procedure (TOP) 01-2-506 Use of Controller Area Network (CAN) Data to Support Performance Testing	**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHORS	**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Automotive Instrumentation Division (TEDT-AT-ADI) US Army Aberdeen Test Center 400 Colleran Road, Building 436 Aberdeen Proving Ground, MD 21005-5059	**8. PERFORMING ORGANIZATION REPORT NUMBER** TOP 01-2-506
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Range Infrastructure Division (CSTE-TM) US Army Test and Evaluation Command 2202 Aberdeen Boulevard Aberdeen Proving Ground, MD 21005-5001	**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)** Same as item 8

12. DISTRIBUTION/AVAILABILITY STATEMENT

Distribution Statement A. Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

Defense Technical Information Center (DTIC), AD No.:

14. ABSTRACT

This document provides guidance for using vehicle-based Controller Area Network (CAN) data during performance and endurance testing of military vehicles. Emphasis was given to use of standard Society of Automotive Engineers (SAE) J1939 CAN data to supplement other available data for vehicle testing, or be used in lieu of data that cannot be obtained otherwise.

15. SUBJECT TERMS

Controller Area Network   sensor   electronic control unit   diagnostic trouble codes   digital interface

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**B. ABSTRACT**	**C. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
Unclassified	Unclassified	Unclassified	SAR	20	

Standard Form 298 (Rev. 8-98)
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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 01-2-506 16 July 2015
DTIC AD No.

USE OF CONTROLLER AREA NETWORK (CAN) DATA TO SUPPORT PERFORMANCE TESTING

1. SCOPE.

This Test Operations Procedure (TOP) provides guidance for using vehicle-based Controller Area Network (CAN) data during performance and endurance testing of military vehicles.

1.1 Purpose.

a. Vehicle CAN data may be used to supplement available test data from traditionally applied (National Institute of Standards and Technology (NIST)-traceable and calibrated) transducers during testing, provided CAN data accuracy is verified, the verification is documented in associated test reports, and use of the CAN data source is stated in the test report identifying the corresponding data channels. Documentation should include sample frequency, full-scale range, and resolution of the CAN data channel. A CAN data channel may also be used in lieu of a traditionally applied transducer channel when the applied transducer fails or becomes inoperable during a test and retesting is not an option.

b. There may be cases of use when the accuracy and frequency of specific CAN data channels cannot be independently verified, such as when vehicle-based controllers provide error messages regarding system functions (e.g., electronic stability control system fault). The information provided by the vehicle-based data channels may be highly valuable information for testing and analysis purposes, particularly when controller diagnostic information is available for analyzing system performance and limitations. In such cases, use of the data are acceptable provided the data source is stated in the test report.

c. The scope of this TOP is limited to the CAN application layer. Network, data link, and physical layer implementations are not addressed.

1.2 Background.

a. A CAN is a standardized digital interface that allows the communication of information in a vehicle between sensors, electronic control units, and computers. A number of sources provide details on the implementation and common message formats, including International Organization for Standardization (ISO) 11898 (Parts 1through 6)[**1] and the Society of Automotive Engineers (SAE) J1939[2,3,4]. The specification CAN 2.0 was published by Bosch in 1991 and was in use when this document was authored. CAN is a message-based protocol with two different formats. The first format uses an 11-bit message identifier and is referred to as CAN 2.0A. The second format uses an extended 29-bit message identifier and is referred to as CAN 2.0B.

** Superscript numbers correspond to Appendix C, References.

b. The SAE J1939 protocol is a variant of CAN 2.0B and is the SAE recommended practice for communication and diagnostics of vehicle systems in the heavy-truck, bus, and off-highway vehicle industry. The J1939 protocol is present in many wheeled military vehicles and is also found on engines used in military generators. The SAE J1939 standards collection (J1939 and J1939 supplemental documents) lays out the format of standard data messages needed to monitor vehicle systems. The J1939 standards also provide the framework for receiving real-time diagnostic error messages and reading historical fault codes from vehicle systems.

c. Besides standard J1939 and CAN messaging, most military vehicle systems also utilize proprietary CAN messages. Typically an interface control document (ICD), defining the proprietary CAN messages, is available from the program management office. The ICD should define the available proprietary CAN messaging and diagnostic messages (DM).

2. INSTRUMENTATION.

2.1 General.

Test instrumentation with traditional user-installed sensors will continue to be used in physical test roles to gather calibration traceable data on system performance. The instrumentation system should be capable of also recording CAN data and diagnostic messaging information. For typical operation, the data acquisition system should remain in a passive state to avoid interaction with any of the controllers on the CAN data bus. If user-installed sensors and CAN data are to be recorded, then the data acquisition system should be capable of simultaneously recording both data types.

2.2 Instrumentation Setup.

The setup of a data acquisition system for CAN bus recording typically starts with defining the desired messages and signals to be recorded. The available signals can be identified by three methods: a database CAN (DBC) file, a vendor-provided ICD, or a scan and analysis of the vehicle data bus. The DBC file type is a common format compatible with most data acquisition and CAN programs. The DBC file contains the description of the connected controllers, messages and signals for the CAN network. If a DBC file is not available, it is good practice to develop a DBC file for each CAN network that will be recorded during testing. A DBC file can be built from the vendor provided ICD and then used to configure the appropriate signal channels on the data acquisition system. If no documentation is available, a scan (using a commercial CAN analyzer) of the CAN data bus provides an overview of available messages and signals. The CAN data bus scan can then be compared to the SAE J1939 and ISO standards to determine the available signals. The number of signals available for monitoring will vary depending upon the age and electrical complexity of the system under test.

2.3 Data Sample Rate.

The data sample rate for the CAN bus varies depending upon the message. CAN is known as an asynchronous data stream, meaning the CAN bus messages and signals arrive at different times and are not synchronized with each other. The samples rates of the data channels are not necessarily consistent and therefore should not be used for any data that requires a frequency domain analysis. The sample rate of the CAN data should be verified before test execution to verify that the CAN data will provide the necessary information to analyze system performance. If data with synchronized time steps are required, then user-installed instrumentation should be added to meet test data requirements.

3. EXAMPLES OF SENSOR DATA USAGE.

The examples below highlight some common CAN data that have been recorded and utilized for vehicle analysis. This is not an exhaustive list.

3.1 Vehicle Speed.

a. The SAE J1939 digital annex[5] lists a data channel in the cruise control/vehicle speed (CCVS) message as an estimate for wheel-based vehicle speed. The wheel-based vehicle speed estimate typically is provided from the engine controller, brake system controller, or both. The wheel-based speed can be verified by comparison to global positioning system (GPS) sensor data, or another calibrated speed sensor installed on the vehicle. The acceptable error for vehicle speed measurement for use during vehicle endurance testing is specified in the instrumentation section of TOP 02-02-505[6]. The acceptable error for data used as a substitute for vehicle performance testing is typically specified in instrumentation section of the appropriate performance TOP.

b. The wheel-based vehicle speed channel is a direct measure of the axle rotation speed. Therefore, in conditions where the tire loses traction with the ground, the reported vehicle speed will not be an accurate indication of vehicle speed. A typical case for using the J1939 reported vehicle speed is when foliage or an obstructed view of the sky causes loss of GPS signal. The wheel-based data can be verified from data collected when a GPS signal was available. An example of this test usage case is presented in Figure 1.

3.2 Engine Speed.

The SAE J1939 digital annex lists a channel in the electronic engine controller 1 (EEC1) message as an estimate for engine rotational speed. The engine speed is provided by the vehicle's engine controller. The engine speed can be verified at idle with the use of a stroboscope, or pulse emitting sensor integrated into the data acquisition system. The acceptable error for engine speed data used in a system performance analysis is typically provided in the instrumentation section of the applicable TOP.

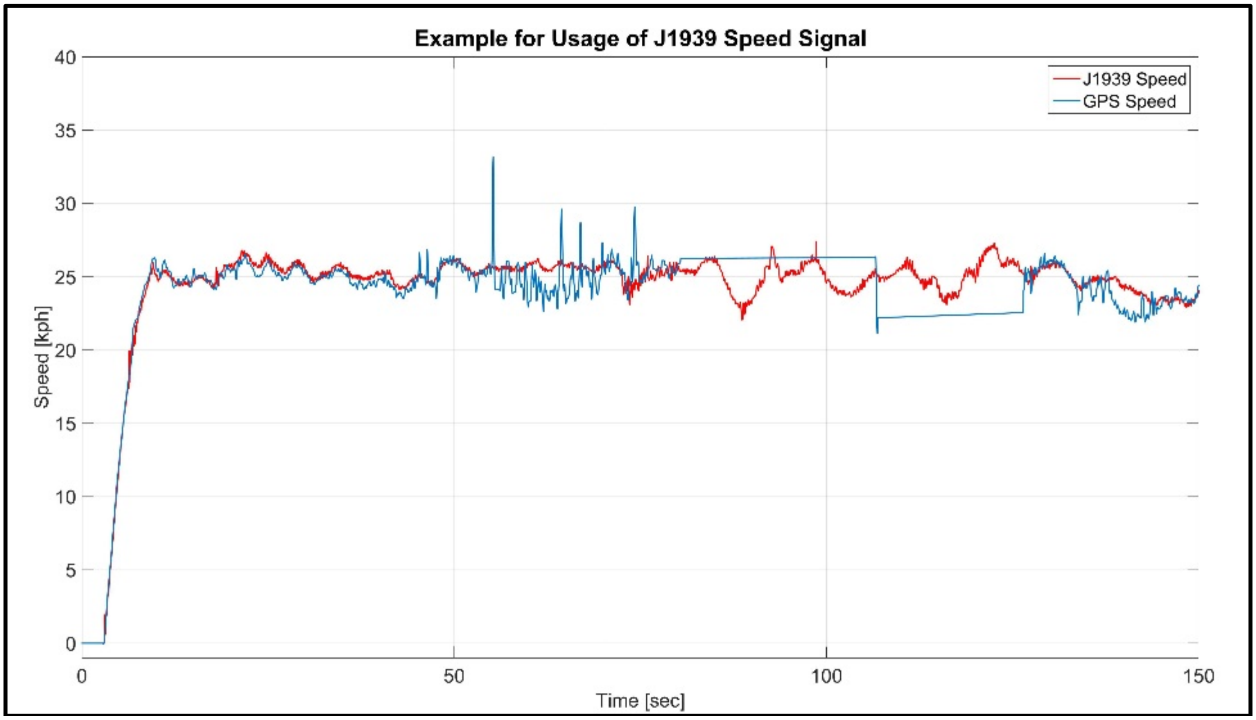

Figure 1. Example scenario for J1939 speed usage.

3.3 Vehicle Odometer.

a. The SAE J1939 digital annex lists several channels that provide an estimate of the distance traveled by a vehicle. The messages are high resolution vehicle distance (VDHR) and vehicle distance (VD). The vehicle mileage messages are often redundantly broadcast on the data bus by multiple controllers. Therefore, the specific distance message should be verified and compared to the actual odometer value shown on the vehicle's gauge cluster unit.

b. The vehicle odometer is typically used for tracking mileage throughout vehicle testing. The odometer reading is used in analysis for distance-based system reliability estimates. Therefore, it is essential to validate that the accuracy of the odometer reading, so that test results between different vehicles systems have a meaningful correlation. The odometer should be verified at a vehicle speed of 70 kilometers per hour (km/hr) as specified in TOP 02-02-505.

3.4 Fuel Consumption.

a. The SAE J1939 digital annex lists several common channels for monitoring vehicle fuel usage. The message fuel economy liquid (LFE) provides a real-time estimate of the vehicle fuel rate and fuel economy. The message fuel consumption liquid (LFC) is a request-based message that provides an estimate of total vehicle fuel consumption. A request-based message requires the instrumentation to send a request to the engine controller to supply the desired message. Another request based message, idle operation (IO), can potentially provide the total idle fuel consumption.

b. Fuel consumption CAN data accuracy should be validated prior to, or during fuel consumption testing using an external fuel flow measurement system (described in TOP 02-2-603A[7]) as a reference. The CAN fuel rate channel should be integrated and compared to the total consumption measured with the fuel measurement system. Scalar correction factors can be determined and applied to the CAN fuel rate LFE message data by averaging or least-squares fitting multiple test runs at different speeds and terrain types. A comparative example of data from an external fuel measurement system (fuel meter), uncorrected J1939 fuel data, and corrected J1939 fuel data are presented in Figure 2.

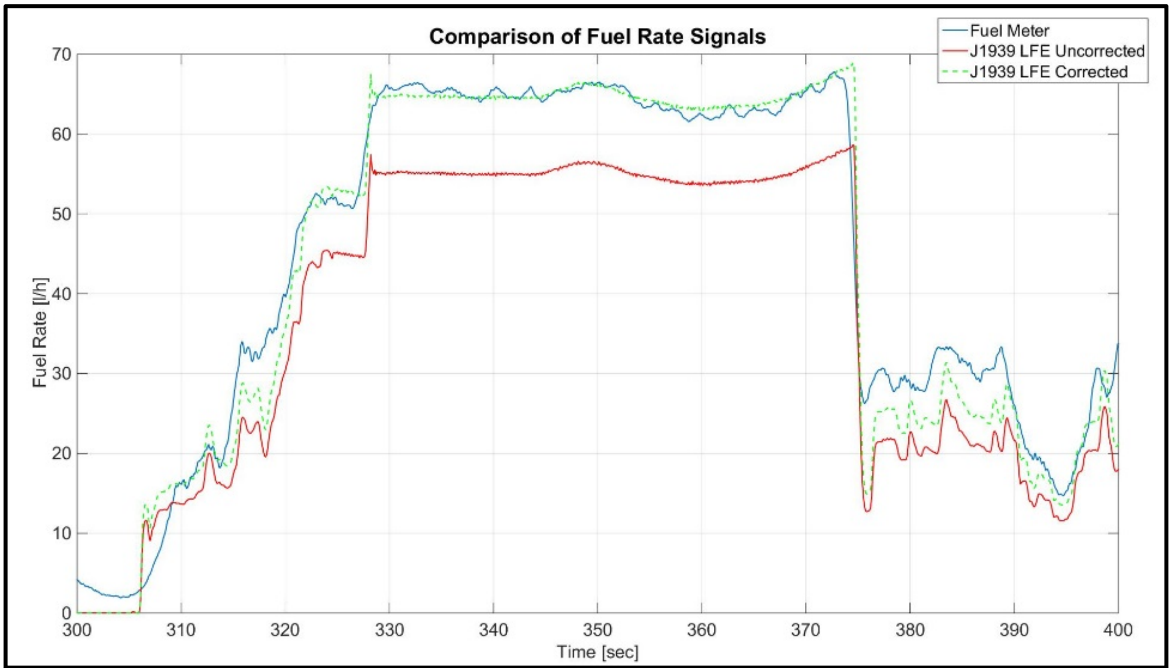

Figure 2. Comparison of fuel rate data.

3.5 <u>Transmission Feedback</u>.

The SAE J1939 digital annex lists messages that monitor transmission operating states. For many performance tests it is important to know the current transmission gear setting, as well as torque converter state. The message electronic transmission controller 2 (ETC2) provides data channels for monitoring the current and selected transmission gears. The messages electronic transmission controller 8 (ETC8) and electronic transmission controller (ETC1) provide information about the transmission torque converter status. The operating state of the torque converter is critical information for powertrain testing. If available on the CAN, this information should be captured for all powertrain related performance testing.

3.6 Vehicle Stability Systems.

a. The SAE J1939 digital annex provides messages that monitor the status and functionality of vehicle anti-lock braking (ABS), anti-slip regulation/traction (ASR), and electronic stability control systems (ESC). The ESC systems are referred to as vehicle dynamic control (VDC) systems in the J1939 documents. The proper functionality of vehicle control systems is necessary for conducting braking, acceleration, and steering and handling performance testing. The message electronic brake controller 1 (EBC1) provides the status of ABS and traction control systems. The message also provides an indication if the brake controller is intervening with vehicle operation. The messages vehicle dynamic stability control 1 (VDC1) and VDC2 provide status information for the vehicle's dynamic stability control operation. The VDC2 data channel provides the active feedback the ESC system sensors. Vehicle steering wheel angle, yaw rate, lateral acceleration, and longitudinal acceleration are also available signals associated with vehicle stability control.

b. The system status signals can be verified prior to testing by disabling the systems and monitoring the state of the fully-operational status channels. The vehicles often provide a switch on the dash to disable the stability or traction control systems. The dynamic signals from the VDC2 message can be verified with the installation of a calibration-traceable inertial system mounted inside the vehicle cab. The inertial system should be located as close as possible to the sensor used for the vehicle stability control system. The data from the two inertial systems are compared for validation of the vehicle's signal data. A comparative example of CAN data used during steering and handling testing is shown in Figure 3. The VDC operational channel indicates that the stability control system was intermittently switching off by the vehicle controller during testing. In one case, the system switched off during a test run. Using the CAN data the test engineer was able to determine that the system was not functioning properly, and which test runs were invalid for analysis purposes.

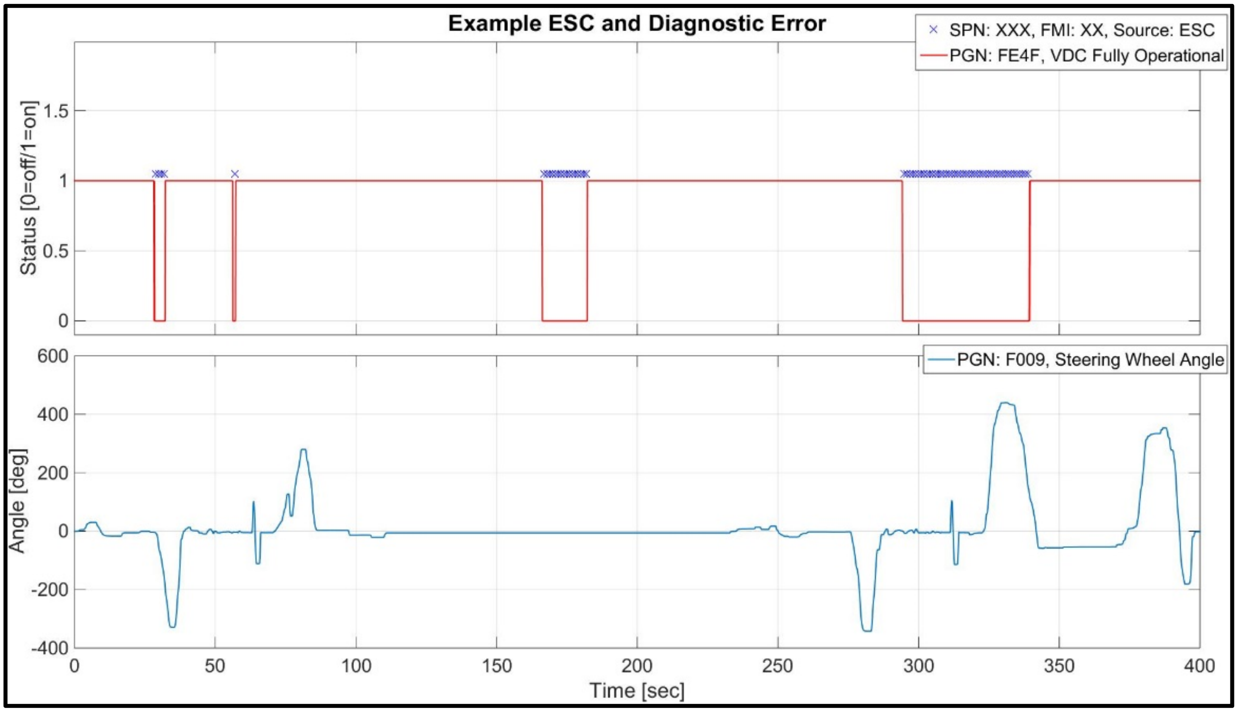

Figure 3. Example of diagnostic trouble codes (DTC) and stability system data.

3.7 Tire Status.

Most military vehicles currently include a central tire inflation system (CTIS). The CTIS is controlled by inputs from the driver based on the vehicle weight and expected terrain type. The CTIS usually broadcasts vehicle tire pressure, driver selected settings, and any system faults. The SAE J1939 digital annex lists the Tire Condition (TIRE) message for monitoring tire pressure and CTIS conditions. Tire pressure is an important data channel to monitor during steering and handling and braking tests. The accuracy of the CAN tire pressure data may be verified by comparing to a calibrated tire pressure gauge. The accuracy should be checked at two different tire pressure settings. The measurements should fall within the tolerances specified in TOP 02-02-704A[8].

4. DIAGNOSTIC DATA USAGE.

a. The J1939 protocol provides standardized reporting of DTCs. The DTC's are integer fault codes that describe the failure type and count of the failure occurrences. DTC's are available in several request-based messages, however this TOP focuses only on the active diagnostic trouble codes message (DM1). The DM1 message provides a method to indicate active faults recognized by the system controllers. The active faults can often be associated with anomalies seen during vehicle performance testing. Not all vehicle diagnostic trouble codes are actively broadcasted. Only DTC's selected by the specific subsystem vendor are actively broadcasted. The DTC provides the suspect parameter number (SPN), failure mode identifier

(FMI), and occurrence count (OC). The SPN and FMI can then be mapped to either a standard contextual definition or a proprietary definition provided in a manufacturer's ICD.

b. An example of DTC used during steering and handling testing is presented in Figure 3. An intermittent fault was present during a steering and handling test. The fault message coincided directly with the disabling of the stability control system. The CAN data provided insight into an intermittent fault that would have otherwise been difficult to recognize and diagnose.

5. DATA REQUIRED.

The CAN data required to support vehicle performance testing is dependent upon the subject of the performance sub-test. All data to be collected should be documented in the test plan, to include the method and instrumentation used, and should be agreed upon by the U.S. Army Test and Evaluation Command (ATEC) System Team (AST). Sections 3 and 4 of this TOP provide examples of data that can be collected from the vehicle CAN.

6. PRESENTATION OF DATA.

The format for data presentation should be determined by the AST. Examples of how data can be presented are provided in Figures 1 through 3 of this TOP.

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APPENDIX A. GLOSSARY

Term	Definition
Failure Mode Identifier (FMI)	The FMI defines the type of failure detected in the subsystem identified by an SPN (SAE J1939-73).
Suspect Parameter Number	This 19-bit number is used to identify the item for which diagnostics are being reported (SAE J1939-73).
Diagnostic Trouble Code (DTC)	A 4 byte value that identifies the kind or trouble, the associated failure mode, and its occurrence count (SAE J1939-73).

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APPENDIX B. ABBREVIATIONS.

ABS	anti-lock braking system
ASR	anti-spin regulation
AST	U.S. Army Test and Evaluation Command (ATEC) System Team
ATEC	U.S. Army Test and Evaluation Command
CAN	Controller Area Network
CCVS	cruise control/vehicle speed
CTIS	central tire inflation system
DBC	Controller Area Network (CAN) database file
DM	diagnostic message
DTC	diagnostic trouble code
EEC	electronic engine controller
ESC	electronic stability control
ETC	electronic transmission control
FMI	failure mode identifier
GPS	global positioning system
ICD	interface control document
IO	idle operation
ISO	International Organization of Standardization
km/hr	kilometers per hour
LFC	Fuel consumption liquid
LFE	fuel economy liquid
NIST	National Institute of Standards and Technology
OC	occurrence count
SAE	Society of Automotive Engineers
SPN	suspect parameter number
TIRE	tire condition
TOP	Test Operations Procedure
VD	vehicle distance
VDC	vehicle dynamic control
VDHR	high resolution vehicle distance

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APPENDIX C. REFERENCES.

1. ISO 11898: Road Vehicles - Controller area network (CAN) - Part 1 through Part 6:

    ISO 11898-1: Data link layer and physical signaling: 2003.
    ISO 11898-2: High-speed medium access unit: 2003.
    ISO 11898-3: Low-speed, fault-tolerant, medium-dependent interface: 2006.
    ISO 11898-4: Time-triggered communication: 2004.
    ISO 11898-5: High-speed medium access unit with low-power mode: 2007.
    ISO 11898-6: High-speed medium access unit with selective wake-up functionality: 2013.

2. SAE J1939, Serial Control and Communications Heavy Duty Vehicle Network - Top Level Document, 14 August 2013.

3. SAE J1939-71, Vehicle Application Layer, 28 April 2014.

4. SAE J1939-73, Application Layer - Diagnostics, 24 July 2013.

5. SAE J1939 - 20150220 Digital Annex (technical data in spreadsheet form), 20 February 2015.

6. TOP 02-2-505, Inspection and Preliminary Operation of Vehicles, 4 February 1987.

7. TOP 02-2-603A, Vehicle Fuel Consumption, 10 May 2012.

8. TOP 02-2-704A, Tires, DRAFT, 31 March 2015.

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APPENDIX D. APPROVAL AUTHORITY.

CSTE-TM 16 July 2015

MEMORANDUM FOR

Commanders, All Test Centers
Technical Directors, All Test Centers
Directors, U.S. Army Evaluation Center
Commander, U.S. Army Operational Test Command

SUBJECT: Test Operations Procedure (TOP) 01-2-506, Use of Controller Area Network (CAN) Data to Support Performance Testing, Approved for Publication

1. TOP 01-2-506, Use of Controller Area Network (CAN) Data to Support Performance Testing, has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency. The scope of the document is as follows:

This TOP provides guidance for using vehicle-based CAN data during performance and endurance testing of military vehicles. Emphasis was given to the use of standard Society of Automotive Engineers (SAE) J1939 CAN data to supplement other available data for vehicle testing, or be used in lieu of data that cannot be obtained otherwise.

2. This document is approved for publication and has been posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

3. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-TM), 2202 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

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FOR

MICHAEL J. ZWIEBEL
Director, Test Management Directorate (G9)

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Range Infrastructure Division (CSTE-TM), US Army Test and Evaluation Command, 2202 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Automotive Instrumentation Division (TEDT-AT-AD-I), U.S. Army Aberdeen Test Center, 400 Colleran Road, Aberdeen Proving Ground, Maryland 21005-5059. Additional copies can be requested through the following website: http://www.atec.army.mil/publications/topsindex.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.